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SEPTIC TANK DESIGN ECONOMIC FACTORS INVOLVED

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Cincinnati, Ohio

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SANITARY ENGINEERING CENTER
CINCINNATI, OHIO

SEPTIC TANK DESIGN

ECONOMIC FACTORS INVOLVED*

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In light of present knowledge, we should discard the idea that there is a single "best" design for a septic tank. Acceptable performance can be obtained with a wide range of freedom in design. For instance, we now know that, within reasonable limits, such factors as shape, liquid depth, and length to width ratios are not the critical items they were once thought to be. Compartmentation may be used either to utilize available units of substandard size, or under certain conditions, to obtain improved performance.

As a number of different designs will give equal performance, selection may be made on the basis of economic considerations. A full-dress economic study would include consideration of sinking funds for replacements, amortization of debt and interest rates, as well as initial cost and frequency and cost of cleaning. Considering the variables and assumptions which would have to be made, an involved study is not justifiable. However, consideration of certain fundamentals might indicate a logical choice of design.

Capacity

The first and most important consideration is capacity. If insufficient capacity is provided, performance will be unsatisfactory. A cycle of loading and unloading of sludge is characteristic of an undersize tank. Sludge accumulates during periods of slow digestion, but most of that accumulation is lost when the rate of digestion increases. This unloading amounts to failure with attendant damage to the disposal field.

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Therefore, it is evident that even before cost is considered, a minimum capacity must be set to insure proper performance. This minimum capacity should be sufficiently large to insure good performance when the tank is receiving the maximum load to be expected. If it is planned to enlarge the house at a later date, the original tank should be large enough to provide service for the expanded house.

When a garbage grinder is, or can be expected to be, connected to the system, recommended minimum liquid capacities are: 750, 900 and 975 gallons for 2 or less, 3- or 4-bedroom homes respectively. If a garbage grinder is an unlikely possibility, capacities can be reduced to 500, 600 or 650 gallons for corresponding house sizes.

In most cases, an economic advantage can be demonstrated for tanks larger than the minimums noted above. Depending on local charges, the cleaning cost is often the overriding factor. The interval between cleanings and thus (for a given job cost) the annual charge for this service is set by rate of accumulation of solids and by the solids storage capacity of the tank.

For example, consider a 2-bedroom home equipped with a garbage grinder. On the average, submerged solids will accumulate at a rate given by the equation:

$$\text{accumulation} = 6.4\ (t) + 8.5$$

where accumulation is in cubic feet and "t" is time in service in years.

A * 750 gallon tank serving this home will give an average cleaning interval of 10.1 years. On the other hand, if a * 1,000 gallon tank is used, the average cleaning period is extended to 15.4 years. Thus, for 33 percent increase in capacity, the cleaning interval is increased 53 percent.

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* Assuming a 5 foot liquid depth and proper penetration of outlet device.

Another example is that of a 2-bedroom house without garbage grinder. A *500 gallon tank will give an average cleaning interval of 9.5 years, but a 750 gallon tank will give an average interval of 19.7 years. The interval between cleanings is more than doubled as a result of 50 percent increase in capacity. Furthermore, at some later date, a garbage grinder could be safely installed without extensive revision of the septic tank. However, additional area would be required in the absorption field.

If the charge made for cleaning and the prices paid for various tanks are known, it is possible to calculate the most economical capacity. The individual costs can be reduced to an annual charge and combined to find the most economical arrangement.

Outlet Penetration

One function of the septic tank is to store solid material which is separated from the liquid fraction of the waste. Some material settles to the bottom of the tank and forms a layer of digesting sludge, while other material floats to the surface and forms a partially submerged mat of scum.

A vertical section of an ideal tank taken just before failure would show it divided into three distinct layers: scum at the top, a middle zone free of solids called "clear space", and a bottom layer of sludge. In effect, clear space is a zone of scour about the bottom of the outlet baffle. Thus the outlet device retains scum in the tank, but at the same time it limits the amount of sludge which will accumulate.

The outlet device must penetrate just far enough to provide a balance between sludge and scum accumulation; otherwise, part of the advantage of capacity is lost. In a tank with vertical sides, this may be accomplished by subtracting a clear space depth from the total depth. The remainder

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* Assuming 4 foot liquid depth and proper penetration of outlet device.

is then apportioned properly between scum and sludge, and the penetration of the outlet device is set accordingly. Values for clear space, scum proportions and an example of their use is given in the appendix of this paper.

Frequency of Cleaning

In the discussion concerned with capacity, it was stated that on the average, a 500 gallon tank serving a 2-bedroom home would need to be cleaned every 9.5 years. The first impulse might be to suggest a 9- to 10-year cleaning period. If such a recommendation were made, a large percentage of these installations would be doomed to premature failure.

Assuming a normal distribution, 50 percent of the installations would run longer than 9.5 years, but conversely, the other 50 percent would never reach 9.5 years. The differences in cleaning intervals is brought about by the differences in individual rates of sludge and scum accumulation. For example, if we consider the rate which is equalled or exceeded by one case out of twenty, we find that the cleaning interval is reduced from the 9.5 year average to 3.2 years or less.

As a rule, in making recommendations concerning these systems, the extreme case rather than the average should be considered. In that way, the recommendation is safe for most of the population. In the matter of cleaning interval, however, this rule does not apply. If a blanket period of 3.2 years was set, there would be no assurance that the one case out of twenty was covered, and the other nineteen cases would be penalized.

A logical solution would depend on periodic inspection so that cleaning could be accomplished as necessary. This is practical if tanks are designed to permit easy access for inspection and cleaning. Manholes and inspection holes should be extended to within 8 inches of the ground surface.

Sludge or scum will be scoured from the tank if accumulation becomes so great that clear space is reduced below the minimum values shown in the appendix. Therefore, an inspection hole should be placed over the outlet baffle so that the depth of accumulation may be related to the outlet penetration.

Scum can be measured with a weighted hinged flap on the end of a stick. A long stick wrapped with rough toweling and lowered to the bottom of the tank will show the depth of sludge. The stick should be lowered behind the outlet baffle to avoid scum particles.

A more accurate measurement can be made with a device similar to that shown in Part I of the report "Studies on Household Sewage Disposal Systems." Although the parts are inexpensive and the device is simple to fabricate, it might not be too practical for the householder to make and use only once a year. However, a sanitarian or a commercial cleaner would find it to be a useful tool.

Multiple Compartments

Although many arrangements are possible, for the purpose of this discussion, compartmentation refers to a number of septic tanks connected in series. These can be either in separate units or enclosed in one continuous shell with water-tight partitions.

Compartmentation has the obvious disadvantage that the installation becomes more complex as the number of units is increased. The most serious objection is, that instead of only one, there are two or more units to inspect and clean.

On the other hand, a compartmented tank will give performance which is at least equal to that of a single compartment tank. This permits a high degree of flexibility. If units of substandard size are available and there is some economic advantage to be gained, they may be added to each other until the desired capacity is obtained.

Some limit must be placed on the size of individual compartments. Otherwise, the situation might be carried to ridiculous extremes. It is recommended that the smallest dimension of any compartment be 2 feet, and that the minimum capacity for any compartment be 125 gallons.

Compartmentation also provides a convenient means for increasing the capacity of an existing tank. Suppose that a 500 gallon tank is being used and it is desired to increase the capacity to 750 gallons. This may be accomplished, without disturbing the existing tank, by adding a 250 gallon unit in series. As will be explained, there is advantage to be gained by placing the smaller unit after the larger. However, if this is impractical, the 250 gallon unit may be placed in front of the 500 gallon tank, and the resulting performance will equal that of a 750 gallon single compartment tank.

When the percolation test shows that a soil is on the borderline for acceptance, or when surface filters or deep seepage pits increase the danger of pollution, a compartmented tank may be used to give maximum protection.

If adequate total capacity is provided, and at least one-half but not greater than two-thirds of that capacity is used in the first compartment, the removal of suspended solids will be substantially increased over that which can be expected from a single compartment tank of equal capacity. The importance of this greater efficiency lies in the fact that soil clogging is proportional to the amount of suspended solids added. Therefore, as the solid content of

the effluent decreases, the likelihood of a long period of trouble-free performance by the disposal field increases.

A compartmented tank should be used in situations where a pollution hazard is created. Septic tank effluent is always dangerous. However, it can be demonstrated that effluent from a compartmented tank is less dangerous than that from a single compartment tank. For example, assume that 8 gallons of raw sewage flows in 1 minute. If perfect mixing is achieved in a 500 gallon tank, the effluent can be expected to contain approximately 1 pint of raw sewage. On the other hand, if the same flow under the same condition enters a 500 gallon tank that has been divided into two equal compartments, the effluent will contain sixty-six thousandths (0.066) of a pint of the raw sewage. Thus, using raw sewage as an index of pollution hazard, the compartment tank effluent is approximately 16 times as safe as that of the single chamber tank.

The preceding statement is based on a mathematical treatment. In a qualitative way, dye tests support the calculations. During a dye test, some dye is recovered in the effluent of a single compartment tank at the initial feed, but with a compartmented tank the presence of dye cannot be detected until a later feed.

Dosing Chamber

Dosing siphons on household systems are unnecessary in spite of the fact that individual discharges are small compared to the total absorption area. For example, a 3-bedroom home equipped with a garbage grinder and an automatic washing machine requires 990 square feet of absorption area in a 60 minute soil (see appendix). This might be done by providing 5 trenches 2 feet wide and 100 feet long. It is obvious that the discharge from any one plumbing unit would not distribute itself over the entire area. However,

it is doubtful that uniform distribution is ever accomplished along the length of the trench by means of the tile line, even in the smaller installations.

In this respect, the bottom of the trench is probably more influential than is generally conceded. It is one of those areas in need of critical evaluation and study.

However, we do know that satisfactory performance has been and is being obtained without the use of a siphon. If the choice were available, I think it would be wiser to invest the cost of a siphon in additional capacity for either the tile field or the septic tank.

Distribution Box

Most recommendations include a provision for a distribution box at the head of the disposal field. The purpose of the box is to insure equal division of effluent to the several distribution lines. In the conventional field, especially on sloping ground, the box is a must to prevent overloading and failure of one line while the others loaf. Pipe fittings, "tees" and "wyes" have been proposed for this purpose, but to obtain even distribution with them is a rare event, if not a virtual impossibility.

The distribution box is a weak spot in the system. It must be carefully installed, otherwise it will defeat its purpose by causing unequal distribution. Furthermore, after installation, the box may settle under a heavy load or be disturbed by a tree root so that distribution is affected.

A number of persons have suggested that by rearranging the scheme of the tile field, the distribution box could be eliminated. In the conventional field, tile lines are connected in parallel and each line is used simultaneously. In the suggested arrangement, the lines would be connected in series, and the first trench would actually start to fail before the second came into play.

The suggestion has a number of theoretical as well as practical advantages. Even after failure, a trench must have some residual capacity for absorbing effluent. In both the conventional and proposed arrangements, this residual capacity is used, but in the conventional any excess results in surface seepage. With the proposed arrangement, excess liquid would spill to the next trench in line until all trenches were used. There is also the possibility that as effluent passes from one trench to the other, it receives additional treatment and becomes more susceptible to soil absorption.

A limited bench scale study has been made and a number of these systems have been installed in various parts of the country. To the best of my knowledge, there are no studies in progress to evaluate those systems, therefore there is little data available.

What information is available looks promising; however, the fact that one of these systems has worked for one year or five years is not very significant. The conventional field is designed for a 20-year life expectancy. The real question is: Will a system which is being used to failure, one part at a time, last as long as a system which is being used all at the same time.

These systems have been used in St. Louis County, Missouri, long enough to provide an answer to that question by making use of proper statistical tools. Unfortunately, for the present at least, no one seems to have the money or the man power to make the study.

Leaching Systems

There are three conventional methods for final treatment of septic tank effluent. In order of their general preference, these are: shallow trenches, deep leaching pits, and subsurface filters. As a general rule, a choice between these three types does not exist. The subsurface filter can always be used as a last resort, but soil conditions will dictate whether shallow trenches or leaching pits can be used.

Shallow Trenches: The preferred system consists of a series of lateral trenches provided with open-jointed distribution pipes packed in coarse durable material such as gravel or stone. As in all leaching systems, the trenches must furnish sufficient soil area for effective effluent absorption, and sufficient storage capacity to handle irregularities in flow. If absorption area is determined by the percolation test in conjunction with the table in the appendix of this paper, sufficient storage capacity for surge flows will be provided.

Shallow trenches are preferable to the other types for several reasons. Danger of ground water pollution is minimized, and full advantage can be taken of evaporation, transpiration, and lateral flow.

On the other hand, a tile field requires a large ground area. The trenches must be located carefully with regard to ground contour and the location of other facilities on the lot. Careful construction is required to prevent damage to the soil and proper slope in the trenches. After installation, the lines are susceptible to mechanical disturbances and damage.

Leaching Pits: In many cases, experience, results of the percolation test, or the presence of a shallow impervious soil layer indicates that a shallow system will not give satisfactory results. Under those circumstances, the soil profile should be investigated to find a deeper layer more favorable for absorption.

A leaching pit is made by digging or boring a circular hole into the deep porous strata far enough to provide adequate absorption area. The walls of the pit are lined with masonry laid without mortar. The bottom is left open, and the top is drawn in with masonry and mortar to a manhole cover. The inlet should be baffled to prevent damage of the opposite wall by jet action.

In calculating the depth of the pit, only the side wall area in the porous stratum or strata should be considered. No allowance is made for the bottom as it will soon become clogged with deposited solids.

Area required is found by first determining the percolation rate and then applying that rate to the table for leaching pits. The percolation test is made in the middle of each different soil stratum as excavation proceeds. Excavation continues until the sum of the areas in the different soil layers is sufficient to absorb the expected volume of effluent.

Seepage pits should not be used in areas where the domestic water supply is obtained from shallow wells or where contamination would affect any water supply. The pit should not be allowed to extend into the water table.

In some areas where a health hazard is not involved, it may be possible to choose between a pit or a shallow trench system. The choice will then be decided on relative construction costs. However, it must be emphasized that factors affecting public health must be equal before the choice is reduced to a dollars and cents basis.

Subsurface Filters: Where investigations disclose that neither the shallow soil nor the underlying strata have adequate absorption properties, a subsurface sand filter is often used. The system should be used as a last resort where a satisfactory means of final disposal of the filtered effluent is available.

A subsurface filter is used as a sewage treatment device rather than a method of disposal. Its function is to further stabilize septic tank effluent so that it is less objectionable for final disposal to a surface location.

The filter is contained in a rectangular bed or series of trenches. Septic tank effluent is applied through an open joint distribution tile system as in the conventional shallow field. The tile is packed in coarse gravel and the entire filter is covered with earth at least 1 foot deep. Clean sand with an effective size of 0.25 to 0.5 mm and a uniformity coefficient not greater than 4 is used for filter material. As a general rule, construction sand will not meet these specifications. Depth of sand ranges between 2 and 3 feet. Filter effluent is collected in an open joint under drain tile surrounded by gravel at the bottom of the filter and carried to the point of disposal.

Subsurface filters are being used in many areas; however, no studies have been advanced to give a factual basis for design. A table is given in the appendix which lists area required for various loading circumstances. The values are derived from a consideration of municipal practice, which is not strictly applicable. However, it is the best information available, and conservative figures have been used to provide a factor of safety.

Encouraging comments have been received from various sections of the country. Subsurface filters are reported to give a well stabilized effluent which is not aesthetically objectionable. In many instances, effluent is being discharged undiluted to dry streams and ditches. To date, I have heard no complaints of odor or insect nuisance in such cases.

An unanswered question is: How long can these covered filters run in the absence of any attention? Municipal experience indicates that they should become clogged quite rapidly. However, systems have been described which were still producing good effluent after five years in service.

There is some evidence that coarse sand is more satisfactory than the finer grades. In several instances, filters clogged soon after installation. They were dug up, the filter material replaced with coarse sand, and put back into operation. The filters then worked to the satisfaction of the owners and the health officials. This experience has led to a recommended effective size of 0.5 to 0.8 mm in a number of localities.

Rejuvenators, Starters, Cleaners, etc.

It is estimated that approximately 1200 of these products are being marketed in the United States at the present time. Various claims are made. Some are sold to start septic tanks, others to speed up digestion, others to clean tanks, and still others to do all three things at once.

There are no yeasts, enzymes or chemical compounds known which will clean a septic tank without doing irreparable damage to most absorption fields.

As for promoting rapid digestion, strange as it may seem, this is not necessarily a desirable condition. Rapid digestion produces a disturbance in the tank which interferes with sedimentation. The desirable condition is to have digestion proceeding at a rate just fast enough to keep up with the applied organic load.

There is need for a convenient available seed material or starter. Odor ranks high among the complaints received, and it appears that odor nuisances are often associated with starting a tank. There is enough technical possibility associated with the idea of preserving and packaging a starter to make the idea interesting.

A number of products are being sold for that purpose, and the Robert A. Taft Sanitary Engineering Center has been requested to test some of them. We have refused those requests. It would be impossible for any Government agency to undertake such a testing program. However, in every instance, we have suggested that the manufacturer contract with a university or other reputable institution to test his product.

Many claims have been made and there is a wealth of testimonial type evidence, but I know of no reliable controlled experiments which will substantiate the statements or claims made.

Conclusion

In conclusion, let me say that there is every indication that septic tanks are here to stay. We may not like it, but there are some six million of these systems in the ground, and they are increasing at the rate of approximately three hundred thousand a year.

Because of its insignificant size the practice is, to take care of the septic tank problem by writing and improving "cook book" style recommendations. Essential as the recommendations are, they will never solve the problem.

Because of its size, the type of loading it receives, and the extremely high standard of performance expected, the septic tank system is a very remarkable sewage treatment plant. It deserves the application of engineering skill and care in design and construction that is extended to its larger city cousin. Unless each individual system is carefully designed, constructed and inspected, it is a potential source of trouble and complaint.

Septic tank complaints rank high in the list of headaches in local health departments all over the country. As long as poor design, misapplication of principles, construction by untrained or unreliable persons, and loose or no inspection at all is permitted, this sore spot will continue to plague us. There are many unanswered questions, but enough information is available to eliminate many complaints before they are ever made.

Another factor over which there is less control, but which is nonetheless important, is maintenance. It is estimated that in more than half the cases, sludge has spilled over and damaged the tile field before the septic tank is cleaned.

The development of factual information is of fundamental importance and must be applied to the design and installation of each system, but all of this is not enough. The home owner must become his own sewage treatment plant operator, or hire some one to shoulder this responsibility for him. For unless the tank is inspected at frequent intervals and cleaned when necessary, the system is riding a probability curve to failure.

APPENDIX

Table 1 - Minimum Liquid Capacities, Household Septic Tanks

No. bedrooms	Min. liq. cap. (gallon)	
	Without garbage	With garbage
2 or less	500	750
3	600	900
4	650	975
Over 4	160/bedroom	240/bedroom

Table 2 - Minimum Clear Space

Surface area of septic tank (LxW) sq. ft.	Sludge clear space ft.	Total clear space ft.
12.5	1.8	2.05
15.0	1.6	1.85
16.7	1.4	1.65
17.5	1.3	1.55
20.0	1.1	1.35
22.5	1.0	1.25
25.0	0.8	1.05
27.5	0.7	0.95
30.0	0.5	0.75
Over 30.0	0.5	0.75

Table 3 - Scum Proportion

Precent of total submerged accumulation that is submerged scum

Without Garbage Grinder	25 percent
With Garbage Grinder	44 percent

Submerged scum is 70 percent of total scum

Example Calculation:

Determine the solids storage capacity and penetration of the outlet device for a 500 gallon septic tank receiving sewage only (no garbage). Total liquid depth is 4.0 ft.

$500 \times 7.5 = 66.7$ cubic feet total capacity

$66.7 \div 4 = 16.7$ square feet surface area

From Table 2 for 16.7 square feet surface area, total clear space equals 1.65 ft.

Effective depth for solids storage

$4.00 - 1.65 = 2.35$ ft.

Capacity for storing solids

$2.35 \times 16.7 = 39.2$ ft.^{3}

Percent of effective depth for solids occupied by scum is 25% (Table 3)

Outlet penetration

$.25\ (2.35) + .25 = .84'$

penetrate 10 inches below liquid surface

Percolation Test:

1. Number and location of tests: Six or more tests shall be made in separate test holes spaced uniformly over the proposed absorption field site.

2. Type of test hole: Dig or bore a hole, with horizontal dimensions of from four to twelve inches and vertical sides, to the depth of the proposed absorption trench. In order to save time, labor and volume of water required per test, the holes can be bored with a four inch auger.

3. Preparation of test hole: Carefully scratch the bottom and sides of the hole with a knife blade or sharp pointed instrument in order to remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Remove all loose material from the hole. Add two inches of coarse sand or fine gravel to protect the bottom from scouring and sediment.

4. Saturation and swelling of the soil: Carefully fill the hole with clear water to a minimum depth of twelve inches over the gravel. By refilling if necessary, or by supplying a surplus reservoir of water, such as in an automatic siphon, keep water in the hole for at least four hours and preferably over night. Allow the soil to swell over night. This saturation procedure insures that the soil is given the opportunity to swell and approach the condition that it will be in during the wettest season of the year. Thus the test will give comparable results in the same soil whether made in a dry or a wet season.

In sandy soils containing little or no clay the swelling procedure is not essential and the test may be made as described under Item 5C, after the water from one filling of the hole has completely seeped away.

5. Percolation rate measurement: With the exception of sandy soils percolation rate measurements shall be made on the day following the procedure described under Item 4, above.

A. If water remains in the test hole after the over night swelling period, adjust the depth to approximately six inches over the gravel. From a fixed reference point measure the drop in water level over a 30-minute period. This drop is used to calculate the percolation rate.

B. If no water remains in the hole after the over night swelling period, add clear water to bring the depth of water in the hole to approximately six inches over the gravel. From a fixed reference point measure the drop in water level at approximately 30-minute intervals for four hours, refilling six inches over the gravel as necessary. The drop that occurs during the final 30 minute period is used to calculate the percolation rate. The drops during prior periods provide information for possible modification of the procedure to suit local circumstances.

C. In sandy soils (or other soils in which the first six inches of water seeps away in less than 30 minutes, after the over night swelling period) the time interval between measurements shall be taken as 10 minutes and the test run for one hour. The drop that occurs during the final 10 minutes is used to calculate the percolation rate.

6. Additional criteria for judging soil suitability: In areas of shallow ground water, the depth to the water table shall be determined. If for any extended period during the year the water table is normally at a depth of less than four feet, the results of the percolation test should be applied with caution. The case also warrants special consideration if impermeable layers are found at depths less than four feet.

Suggested design areas for soil absorption trench type systems are presented in Table 3. These take into account recent water consumption data, effects of garbage grinders, and automatic sequence washers, the original Ryon allowable sewage loading data (5), and additional data on clogged systems, treated by modern statistical approaches to arrive at the values given.

Table 4 - Percolation rate and design absorption areas

Percolation rate, (time required for water to fall one inch - in minutes)	Required absorption area (Square feet of absorption trench bottom per bedroom)			
	Without garbage grinder or auto. washer	With garbage grinder	With auto. washer	With both garbage grinder and auto. washer
2 or less	50	65	75	85
3	60	75	85	100
4	70	85	95	115
5	75	90	105	125
10	100	120	135	165
15	115	140	160	190
30	150	180	205	250
45	180	215	245	300
60	200	240	275	330
Over 60	Unsuitable for shallow absorption system. Investigate for seepage pit or subsurface filter arrangement.			

Table - 5 Areas for subsurface filters

Load	Area per bedroom - ft.
Without garbage grinder or automatic washer	150
With garbage grinder	170
With automatic washing machine	200
With both garbage grinder and auto. washer	230